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Current Opinion in Environmental Sustainability

A brief review of health-related issues occurring in urban areas related to global warming of 1.5°C

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Recent publications are reviewed in the context of urban health issues possibly resulting from global climate change. The most important phenomena having an impact on health discussed in the paper include increased ultraviolet radiation due to stratospheric ozone, temperature-related effects, precipitation-related effects (both excessive precipitation and drought), vector-borne diseases, and finally air quality, smog-related effects. Among the above, those most directly linked to climate change may be associated with temperature-related and precipitation-related effects. The paper points out that even with 1.5°C warming major health impacts can be expected. Among the most important are respiratory problems (such as asthma) and increase in vector-borne diseases especially through ticks. In addition, urban expansion due to population increase projects urban heat island intensity increase superimposed on global warming.

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Current Opinion in Environmental Sustainability 2018, **30**:123–132

This review comes from a themed issue on **1.5°C Climate change and urban areas**

Edited by **Diana Urge-Vorsatz** and **Karen Seto**

For a complete overview see the Issue and the Editorial

Available online 7th June 2018

Received: 10 July 2017; Accepted: 11 May 2018

https://doi.org/10.1016/j.cosust.2018.05.014

Introduction

According to United Nations reports and data available online (http://www.un.org/en/index.html) the majority of the population lives in urban areas, and the ratio of the urban to rural population is projected to increase with the total urban population estimated to increase to 6 billion by 2050. Therefore, it is essential to provide realistic estimations of future climatic conditions that involve severe consequences to human health (e.g. [1]) in urban areas. Any necessary local adaptation plans should address location-specific issues, and already the health aspects and local adaptation plans have been discussed for five cities with a Mediterranean climate (Adelaide, Australia, Barcelona, Spain, Cape Town, South Africa, Los Angeles, USA, and Santiago, Chile [2]).

Global warming affects many allergens (e.g. pollens) and various infections (e.g. malaria, diarrhea, meningitis, dengue fever) [3]. Furthermore, global climate changes can cause severe catastrophes due to intense precipitation or, on the contrary, a long-lasting lack of precipitation. A more direct consequence of warming climatic conditions is the increase of the frequency and intensity of heat waves, which is already a major threat in the densely populated cities of the Middle East, India, and East-Africa [3]. In the northern midlatitudes heat waves were overall less frequent in the previous centuries, however, due to the unusually warm summers of recent years, more focus has fallen on this issue both in Europe and North America, and the climate projections suggest a further increase in the duration and frequency of heat waves [3]. In some locations the effects of fast urbanization contribute substantially to regional warming, which, coinciding with global warming, strengthen the local temperature increase resulting in a positive feedback mechanism. The concentrated anthropogenic activities in cities are major sources of greenhouse gas emissions as well as of local air pollutants. Thus, the health issues related to air pollution must also be addressed in urban areas. Table 1 provides a basic overview of the direct and indirect health-related effects of climate change together with the main health symptoms. In addition, it lists recent references mostly from the last 2–3 years, which were identified with an online search in related articles for the keywords: urban, health, climate change, heat wave, vector-borne, smog, which was then followed by an author search of the most relevant literature found in the initial keyword search. Many of the papers found focus on small segments of the entire issue, and generally fail to specifically address both the 1.5°C, and the 2°C global warming targets. Instead, it was more common to find an analysis related to the changes detected or to the new Representative Concentration Pathway (RCP) scenarios [4], among which RCP2.6 can be considered as the most competent scenario resulting in climatic conditions in the 21st century that are similar to the target mitigation scenarios.

The aim of this paper is to summarize and provide an overview of a representative selection of recent studies that specifically focus on the actual health issues in urban areas and also address global warming related consequences at the same time. The comparison and synthesis

Table 1

The main direct and indirect effects of climate change on health in urban areas

	Health symptoms	Specific references with related research
Direct effects		
Radiation-related	Cataracts, skin cancer	Iglesias-Suarez *et al.*, 2016 [5]
UV (stratospheric ozone)		Lucas *et al.*, 2015 [6]
		Butler *et al.*, 2016 [7]
		Bais *et al.*, 2015 [11••]
		Meul *et al.*, 2016 [12]
		Nowack *et al.*, 2016 [13]
Temperature-related	Cardiovascular stress	Wang *et al.*, 2017 [14•]
Heat stress	Freezing	Schleussner *et al.*, 2016 [15••]
Cold stress		Sun *et al.*, 2016 [16]
		Lin *et al.*, 2016 [17]
		Hatchett *et al.*, 2016 [18]
		Arima *et al.*, 2016 [19]
		Mirzaei, 2015 [20]
		Taleghani *et al.*, 2015 [21]
		Lauwaet *et al.*, 2016 [22]
		Kunz-Plapp *et al.*, 2016 [23]
		de Munck *et al.*, 2017 [24]
		Carvalho *et al.*, 2017 [25]
		Quinn *et al.*, 2014 [26]
		Diem *et al.*, 2017 [27]
		Wang *et al.*, 2015 [28]
		Bao *et al.*, 2015 [29]
		Dong *et al.*, 2014 [30]
		Smith *et al.*, 2016 [31]
		Chen *et al.*, 2017 [32]
		Zhang *et al.*, 2018 [33]
		Urban *et al.*, 2016 [34]
		Austin *et al.*, 2016 [35]
		Panic and Ford, 2013 [36]
		Schuster *et al.*, 2017 [37]
		Fernandez Milan and Creutzig, 2015 [38]
		Vicedo-Cabrera *et al.*, 2018 [39]
		Emmanuel, 2017 [40]
		Masson *et al.*, 2014 [41]
Precipitation-related	Drowning	F: Burger and Gochfeld, 2017 [42]
Excessive — storm, flood (F);	Dehydration	F: Feng *et al.*, 2015 [44]
Scarce — drought (D)		F: Ma *et al.*, 2015 [45]
		F: Chen *et al.*, 2016 [46]
		F + D: Schleussner *et al.*, 2016 [15••]
		F + D: Güneralp *et al.*, 2015 [47•]
		D: Davis *et al.*, 2016 [43]
		D: Carrao *et al.*, 2016 [48]
		D: Gober *et al.*, 2016 [49]
		D: Kahil *et al.*, 2015 [51]
		D: Mortazavi-Naeini *et al.*, 2015 [52]
Indirect effects		
Vector-borne infections, disease	Malaria, dengue fever,	Patz *et al.*, 2005 [3]
	tick-borne encephalitis	Schlagenhauf *et al.*, 2015 [53]
		Al Ahmed *et al.*, 2015 [54]
		Yeryan *et al.*, 2016 [55]
		Pakdad *et al.*, 2017 [56]
		Pradier *et al.*, 2012 [57]
		Piperaki and Daikos, 2016 [58]
		Medlock and Leach, 2015 [59•]
		Liu-Helmersson *et al.*, 2016 [60]
		Ebi and Nealon, 2016 [61]
		Jia *et al.*, 2017 [62]
		Alimi *et al.*, 2015 [63]
		Ren *et al.*, 2016 [64]
		Hundessa *et al.*, 2018 [65]
		Paz, 2015 [66]
		Parham *et al.*, 2015 [67]

Table 1 (*Continued*)

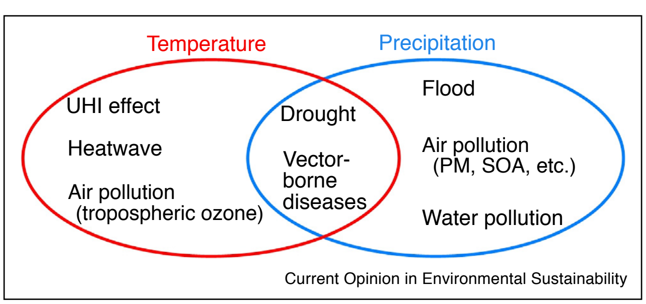
	Health symptoms	Specific references with related research
Allergen Pollens, fungae, dust mite	Asthma, respiratory problems	Patz *et al.*, 2005 [3] D'Amato *et al.*, 2015 [68] D'Amato *et al.*, 2016 [69] Touchaei *et al.*, 2016 [64] Pandey *et al.*, 2017 [74]
Pollution Air — urban smog (tropospheric ozone) Water — drinking water, food production	Asthma, respiratory problems Water-borne infections (vibrios, parasites, bacteria, viruses)	He *et al.*, 2016 [70] Lee *et al.*, 2017 [71] Diem *et al.*, 2017 [27] Touchaei *et al.*, 2016 [72•] Horne and Dabdub, 2017 [75] Dawson *et al.*, 2016 [76] Shi *et al.*, 2016 [77]

of such studies are extremely challenging because the literature available is very diverse in the terms of target area, analyzed period (both reference and target), and applied methodology. Because of the length constraints this review cannot systematically review the burgeoning literature of the past few years, but will highlight a number of key developments and illustrate these in some case studies. We have structured this paper according to the health-related consequences originating from the main aspects, namely, stratospheric ozone, temperature and precipitation conditions, vector-borne diseases, and urban air quality, including smog events. Figure 1 provides a simple schematic overview of the major environmental effects mentioned above, which are reviewed here with respect to urban areas and linked to the main climatic variables (i.e. temperature and precipitation).

Stratospheric ozone

The successful series of international treaties starting with the Montreal Protocol in 1987 (which entered into force in 1989) seem to have solved the well-known problem of stratospheric ozone depletion over the course of a century time scale [5], however, the increased level of ultraviolet (UV) radiation will continue to affect human health in the coming decades [6], and the concentrated population of urban areas will still develop cataracts and skin cancer, which will require medical treatment. A comparison study [7] of the projected changes of the UV index (expressed as a function of total column ozone) based on the simulation results of global climate models (GCMs) using the RCP scenarios [4] indicated that the ozone layer would certainly benefit if the CO_2, CH_4 and N_2O emission reduction goals were fulfilled according to the RCP2.6 scenario, which roughly estimates a 1.5°C global warming by the end of the 21st century relative to the pre-industrial climatic conditions [8]. Specifically, the global increase in CO_2 concentration is resulting in stratosphere cooling, and so ozone-depleting reactions are slowing down, with ozone presence generally increasing by a few Dobson Units [9]. However, opposite changes also exist, which are related to the increase in concentration of N_2O as the major ozone-depleting substance due to it being the primary natural source of stratospheric NO_x [9]. A coupled chemistry-radiation-dynamics model simulation [10] indicated that the overall stratospheric ozone level depends on the relative ratio of CO_2 and N_2O concentration changes.

Figure 1



Health-related environmental effects linked to the two main climatic elements in urban areas.

A study [11••] pointed out that a possible decrease of solar activity in this century might further influence UV radiation at the surface. However, aerosols are probably the most important factor for projecting UV radiation (aerosols absorb and scatter incoming radiation including both visible light and UV), especially over the most populated urban areas. Because of the expected improvement in air quality (thus a decrease in anthropogenic aerosols), the estimated increase of UV-B radiation near the surface is generally 10–20% in large cities in the northern hemisphere [11••]. It was also noted in this study that the uncertainty of estimations associated with the aerosols is quite high [11••], especially because of organic aerosols.

RCP4.5, RCP6.0 and RCP8.5 project lower stratospheric ozone content over the tropics by the late century compared to the 1960s [12], which may result in a 15% increase of UV radiation in specific tropical regions. On the one hand, the solar radiation management techniques (e.g. [11••]) may compensate the global warming induced by the anthropogenic greenhouse gas effect. On the other hand, stratospheric ozone is estimated to increase and result in a large

decrease in UV radiation [13], so an adverse health effect may occur due to vitamin D deficiency.

Temperature-related effects

The urban heat island (UHI) effect is usually characterized by the temperature difference between the central regions of a city and the surrounding rural areas. Moreover, the increasing intensity and frequency of local heat stress (e.g. [14•]) together with decreased cold stress are probably the most straightforward consequences of global warming. The global mean warm spell duration indicator (WSDI), which can be linked to the length of heat waves (i.e. the annual number of consecutive days when the daily maximum temperature for each day exceeds the 90% percentile value calculated from the reference period), is estimated [15••] to become 1.1 months in the case of a global warming of 1.5°C relative to the preindustrial climatic conditions. In comparison, an estimated average duration of 1.6 months is linked to the 2°C global warming scenario [15••]. The globally averaged difference of 0.5 months between the projected heat wave durations may increase locally, and, for instance, the difference between the projected durations in tropical regions doubles as 2-month (for the 1.5°C global warming scenario) and 3-month (for the 2°C global warming scenario) heat waves are projected [15••]. The temperatures of the monthly hottest days are projected to further increase by 0.6–1°C in Europe and North America [14•] if global warming increases from 1.5°C to 2°C, which is projected to occur in the very next few decades according to RCP8.5 and RCP4.5.

The UHI effect and global warming reinforce each other, thus, the detected warming in cities consists of these two sources. For instance, a total mean warming of 1.44°C was detected in China during 1961–2013 [16], of which about 0.49°C can be considered to come from urban effects [16]. More specifically, the analysis of the contribution of expanding urbanization in three agglomerations in China (Beijing, Shanghai, and Guangzhou) identified a contribution of about 10% to the 30-year (1980–2009) warming trends [17]. When focusing on the central cities themselves, the greatest contribution of urban warming was found in Shanghai with almost 30% [17] from the total warming during the analyzed period. A quantile-mapping bias correction method was applied to global climate model outputs to provide temperature projections for cities [18] with substantial UHI effects. Regional climate model experiments embedded in global climate models (the nesting of level 1 started at 54 km, and level 4 ended at a horizontal resolution of 2 km) analyzed the future summer conditions of Tokyo in 2026–2035 [19]. This specific study used the RCP4.5 scenario, however, within this short timeframe the projected global mean warming can be considered to be around 1.5°C. The results for a two-storey detached house showed a 26% increase of total sensible heat load and a 10% increase of latent heat load in August [19].

In general, the UHI effect is often analyzed by using meso-scale models, however, as [20] concluded, their accuracy is still not sufficient to provide a detailed representation of the urban canopy layer (i.e. the main active surface of urban areas). The structural characteristics of the city play a key role in the determination of the outdoor thermal comfort of individuals. Singular, linear and courtyard urban forms within the Netherlands have been analyzed on a microclimate scale [21]: the results pointed out that the courtyard form provides the most comfortable climatic conditions in warm summer days. The Brussels UHI was analyzed [22] using recent past (2000–2009) and future (2060–2069) climate conditions driving an urban boundary layer climate model using very fine resolution (i.e. 250 m). The results suggest that the UHI intensity is likely to decrease slightly with global warming, which can mainly be explained by increased incoming longwave radiation due to warmer and more humid air [22]. A very important consequence of the relationship between UHI and global warming is the projected impact on the frequency of extreme heat [22], specifically, the number of heat wave days in urban areas increases faster (about twice) than in the rural areas.

A survey study conducted about the subjective perception of heat stress in Karlsruhe, Germany, identified the most important factors [23] to provide guidance on building long-term strategies to reduce urban heat stress. The results highlighted the role of green space [23]. [24,25] also emphasized the use of green (and white) roofing when analyzing the effectiveness of several resilience strategies for mitigating extreme heat stress in urban areas. It is important to point out that indoor temperature conditions may be controlled during extreme heat waves, however, this option may not be feasible or affordable for all the different social groups [26]. A discussion of the heat effects in the southeastern U.S. emphasized that the extreme high temperature conditions are already present during summer [27]. The conclusions projected an increase in regional temperature (including summer), and consequently a clear increase of heat-related health issues [27]. Extreme high temperatures cause severe environmental stress for people with hypertension [28].

The heat vulnerability index is reviewed in detail [29] on the basis of 15 studies focusing mainly on Europe and the U. S. The conclusions pointed out that heat-related indicators can be used to identify the social groups at the greatest potential risk due to heat, and it is important to perform assessments in as many regions and countries as possible [29]. The analysis of the health effects of the UHI in Beijing clearly showed a much greater heat health risk in the urban area compared to the rural area [30], and therefore, suggested general and Beijing-specific actions to mitigate public heat health risk. The two main responses [30] include changing the environment, and reducing vulnerability. Conclusions from the impact analysis of heat waves

in England drawn by comparing morbidities due to asthma, cerebrovascular accident and cardiovascular symptoms in a hot year (i.e. 2013) to those in less hot years (i.e. 2012 and 2014) highlighted the difficulties in identifying those individuals who might be at a higher risk of suffering from the non-fatal health effects of heat stress [31]. Mortality data (considering four types of diseases, namely, cardiovascular, cerebrovascular, ischemic heart, hypertensive) are compared from the two most populated municipalities in China (Beijing and Shanghai) for a relatively short period (2007–2009), and strong associations with temperature were found both in the cold and hot ranges [28]. An analysis of projected heat-related mortality was performed (for cardiovascular, respiratory, stroke, ischemic heart disease, and chronic obstructive pulmonary disease) for the urban and rural counties of Jiangsu province (where Shanghai is located) in the 2016–2040 and 2041–2065 periods [32] relative to the 1981–2005 historical period using RCP scenarios (the earlier target period can be considered to represent the 1.5°C global warming). The results in [32] point out that due to regional warming nonurban residents in Jiangsu are likely to suffer more from heat-related mortality than urban residents. The temperature-related mortality due to cardiovascular disease (CVD) is projected for the other Chinese megacity, Beijing in [33] using 19 GCM simulations with different RCP scenarios (RCP2.6, RCP4.5 and RCP8.5). The results clearly highlight an overall future increase in mortality because the cold-related decrease of CVD deaths will not be able to compensate the heat-related increase of CVD deaths, which is valid even in the case of RCP2.6 (when the smallest global warming, close to 1.5°C, is projected). To mention another example from Europe, the conclusions drawn from detected heat-related cardiovascular mortality in the Czech Republic (located in Central Europe) between 1994 and 2009 highlight the significant lagged effect of high temperatures in the most urbanized regions [34].

Adaptation strategies for climate change include many health-related issues. The national-level public health adaptation already implemented in OECD (Organization for Economic Cooperation and Development) countries is examined in [35], with cross-sectoral collaboration, vertical coordination and national health adaptation planning also being evaluated. These strategies primarily focus on infectious diseases and heat-related risks [36]. According to [37] health and fitness are the most important factors in adaptation to the heat stress on the individual level rather than age. A thorough review [38] concluded that strong coordination between public health and urban planning may effectively manage the increasing risks of future heat waves. Adaptation potentials are highlighted in [39] since a detailed analysis of heat-related mortality impacts over 300 locations in 10 countries worldwide showed a decrease in the past decades, which is assumed to be the result of successful adaptation to temperature increase already detected.

It was pointed out in [40] that air conditioning against the heat in tropical cities causes further problems because the additional anthropogenic heat of the indoor cooling warms the outdoor air. An interdisciplinary systemic modeling approach (namely, coupling socioeconomic, geographical, architectural, building energy use, urban climate and atmospheric models) is used to address the adaptation of cities to climate change in a more general sense [41]. One of the main conclusions is that the strategies should address different processes and they may also need to be modified over time. For instance, although green belts will be efficient structural elements in urban planning in the next few decades, they will produce the negative impacts for growing cities over longer time scales [41].

Precipitation-related effects

On the one hand, precipitation may directly affect the urban population when injuries occur due to extremely strong storms with intense rain (e.g. [42]), which then possibly continue as floods. As a consequence, in addition to injuries, buildings may be damaged, transportation can be obstructed, etc. In [15••] a 7% (10%) increase in heavy precipitation intensity was estimated to occur in South Asia in the case of the 1.5°C (2°C) global warming scenario. On the other hand, indirect effects may also occur, namely, the lack of water during droughts hinders agriculture and prevents food production [15••,43]. The lack of safe drinking water may cause severe infections and increase water-borne disease.

Urbanization causes rapid land cover change on the regional scale, and consequently results in increased surface thermal heating to the atmosphere (2–3°C), which ultimately affects large scale phenomena, for example, the Asian monsoon via the modified surface energy budget. Several studies (e.g. [44–46]) performed climate model experiments for eastern Asia and showed that the early summer precipitation is likely to increase in northern and northeastern China, and decrease in the regions that are located south of 35 °N due to the projected changes in the East Asian summer monsoon system. Then, the precipitation in August is projected to decrease over a quite extended area located north of 25 °S (NE-China, Korea, Japan), and increase in south China and over the South China Sea. Thus, the urbanization-induced changes affect the climate outside of the urban area as well as in urban regions.

According to the conclusions of a global estimation [47•] of the changing exposure of urban areas to floods and droughts due to land cover changes (i.e. urban expansion) between 2000 and 2030, the urban area exposed to flood and drought hazards will increase in these 30 years 2.7 and 2 times, respectively. The area of cities that is exposed to both flood and drought is likely to increase over 2.5 times [47•] in the analyzed period. The study [47•] does not consider the

usual scenarios used in IPCC reports (which do not differ remarkably until 2030 anyway), and only takes into account the estimated expansion of urban areas.

A 9% reduction in the annual water availability in the Mediterranean region was estimated in [15••] in the case of a global warming of 1.5°C relative to the preindustrial climatic conditions. The 2°C global warming scenario is likely to result in almost a double (17%) reduction of the water available in the Mediterranean region [15••]. Other subtropical regions with dry conditions (e.g. Central America, South Africa) will face similar risks [15••]. According to the conclusions in [48], a higher drought risk is present in the populated areas, especially in South-Central Asia, Central Europe, the southeastern parts of South America and the U.S. Then a case study was shown in [49] using an anticipatory water policy and planning model (called WaterSim5 [50]) for Phoenix (U.S.) that surprisingly stated that cities may still flourish during the consecutive, long dry periods likely to occur in the region in a time frame of a few decades due to global warming. Other results, like those included in [49] highlighted the importance of long-term planning and a detailed policy for adaptation to the environmental changes associated with generally warmer conditions. Focusing on the south-eastern region of Spain a hydro-economic model was applied in [51] to analyze drought impacts and assess alternative adaptation policies. Additionally, the urban water supply is modeled for increasing drought conditions in an Australian bulk water system [52], the conclusions highlighted that besides the uncertainty of future climate change other aspects (i.e. water demand) also play an important role.

Vector-borne disease

The effect of global warming on the spread of vector-borne diseases (i.e. transmitted typically by ticks or mosquitoes) can already be detected. For instance, many cases of infection (e.g. dengue and chikungunya virus) have started to occur in Europe that were previously extremely rare or even unprecedented. Most of these cases may possibly be associated with more frequent travelling and transportation to/from the endemic areas [53–56]. Other infections may have occurred due to the migration of host animals. To mention two examples: the West Nile virus appeared in Eastern Europe [57] and malaria recently reemerged in Greece [58]. The current status of the various vector-borne diseases and the corresponding consequences of a 2°C warming are summarized in [59•], the analysis focuses mainly on the UK with some broader context within Europe. The future projections are evaluated in [60] specifically for dengue epidemic potential in European cities, and the role of the mitigation of greenhouse gas emissions is also highlighted in reducing the future epidemic potential. Evidently, expansion is primarily projected along the present geographical edges of dengue distribution [61] where temperature is likely to increase and precipitation pattern to change in favor to the vectors [62].

Specifically malaria-related issues are discussed for South America [63] and China [64,65], and although the ranges of malaria-host mosquitoes are projected to expand in the northern parts of South America, the malaria-affected area is estimated to decrease [58] due to potentially improved health care systems. In the other study [64] RCP scenarios are taken into account to estimate the environmentally suitable area of malaria vectors in China in the 2030s and the 2050s. Because of the projected land use changes and the simultaneous urbanization, a substantial net increase of population exposed to malaria is projected [64] by 2030s even when considering a mitigation scenario (i.e. RCP2.6) with a global warming close to 1.5°C. Then [66] focuses on the West Nile virus from a global perspective: the number of epidemics is estimated to increase with global climate change because of the endemization process in various locations in southern Europe, western Asia, the eastern Mediterranean, the Canadian Prairies, some parts of the U.S. and Australia due to increased temperature and fluctuations in precipitation.

Because of the length constraints, a very detailed review cannot be accommodated into this paper, however, the impacts of global warming on vector-borne diseases including future transmissions, uncertainties and challenges are discussed in depth in [67].

Smog, air quality

The relationship between climate change and respiratory diseases is highlighted in [68], these conditions are the most evident health effects of the anthropogenic environmental changes [69]. Various models are coupled to analyze the complex problems associated with climate change and air pollution, namely, air chemistry models with climate models (e.g. [70]). The analysis of projected mortalities for the future periods of 2016–2025 and 2046–2055 due to surface ozone concentration changes and heat stress in seven major cities in South Korea using RCP scenarios [4] concluded that mortality is less sensitive to ozone concentration than temperature increase [71]. The detected and projected ozone concentrations together with the UHI in summer are discussed for the southeastern U.S. cities in [27] with the conclusions showing that high ozone concentrations are likely to occur during future heat events, which are expected to be intensified by the UHI. A regional model was used in [72•] with special focus on air quality (i.e. regional climate model coupled with atmospheric chemistry) to analyze the effect of increased urban albedo on the concentration of different pollutants (e.g. PM2.5 and ozone) for Montreal. The model simulation outputs showed that an appropriate mitigation, namely, an increase of 0.25–0.45 in the albedo of urban surfaces (roads, roofs, walls) results in substantial temperature decrease during heat wave periods, but

negligible changes in ozone concentration, which is due to the opposite effects of the decreased height of the planetary boundary layer (PBL) and the decreased ozone production rate because of the decreased temperature [72•]. The results of [72•] also suggested a slight improvement of air quality when the PM2.5 concentration (its vertical distribution can be determined more precisely using lidar technology (e.g. [73]) strongly depends on PBL height. Then the health effects of PM10 are discussed in a special case in Varanasi, India in [74]: which states that some particles (heavy metals) have carcinogenic effects, and highlights the connection to the toxicity of the environment. The results pointed out that the exposure concentration of PM10 is the highest near the industrial region of the city [74], the concentration in the residential area is less, whereas the least concentration can be detected on the university campus. In addition to ozone and PM, secondary organic aerosol (SOA) concentration is also analyzed for California [75]: the results showed that the afternoon ozone concentration is projected to increase from 2005 to 2023, PM concentration changes are rather negative (but strongly depend on the actual location within the region), and SOA concentration is projected to decrease. SOA is the main focus of [76], which uses an Eulerian chemical transport model with a 5 km horizontal resolution.

Managing and preventing smog events are high priority due to the associated health effects to be avoided. An interdisciplinary approach was developed in [77] for the mitigation of smog on the basis of 54 particles classified into eight large groups, which approach can be applied to China or other regions of the Earth. It was highlighted in [14•] that not only should the total radiative forcing changes and the resulting warming be considered when evaluating the difference between the 1.5°C and 2°C global warming scenarios, but also the chemical compositions of the emission scenarios.

Concluding remarks

During the past few decades health impacts induced by warming have already occurred worldwide. Many case studies can be found to identify the link between health related impacts and climate change (e.g. [78]). For instance, on the global level heat-related mortality has already increased, while cold-related mortality has decreased in many areas. Involved in this is the tendency of more frequent and more intense heat waves (e.g. [27]). The model simulations suggest that even with an immediate drastic reduction of anthropogenic emissions of greenhouse gases, the detected trends are likely to continue for a few decades at least. The new long-term target of 1.5°C global warming relative to the pre-industrial era is projected to occur in the very next few decades (when considering either RCP4.5 or RCP8.5) and this is only a viable estimation if RCP2.6 becomes more realistic in the very close future, within a decade or so. The global warming detected is already close to the long-term target future temperature increase of 1.5°C, which implies further temperature changes and consequently even more increased impacts are set to come. Also it should be noted that the relationships between causes and effects are often non-linear, hence the future consequences may be much greater [14•] than what one would expect on the basis of a simple extrapolation.

The effect of global warming must be evaluated jointly with the urbanization processes in order to assess the local climatic changes of urban areas. Due to the nonlinearity of interrelationships, the combined effects of global warming and urbanization are likely to intensify even small global temperature changes on the local scale. It is important to highlight that the contributions of UHI intensity increases to the locally detected temperature trends are quantified for the past decades in the large cities of China (10–30% was found by [16,17] in addition to the regional effects of global warming, the varying results are due to the different time periods and cities involved in the analysis). Since further urban expansion is expected from the population increase, the projected UHI intensity increase will be a key part of future warming superimposed on global warming. In other places where a population increase is not projected (for instance in Europe), the meso-scale models conclude UHI intensity decreases along with global warming (e. g. [22]), especially if a reduction in UHI intensity is implemented with more green spaces and/or white roofs (e.g. [24,25]), meaning that the local temperature increase would be less than the global warming rate. However, such surface cover changes are highly dependent on local strategies and decisions that add further uncertainty to urban climate projections.

An opposite effect can be foreseen (especially in tropical cities) due to the increased use of air conditioning, which is superimposed on the global warming, leading to local positive feedback [40].

Science, with appropriate professional communication techniques, can modify public perception of the threat of climate change, which ultimately alters decision-makers to be committed and act to reduce greenhouse gas emissions and decrease the overall anthropogenic radiative forcing. Key public health recommendations were listed in [79], which are especially important in cities where the population is concentrated. It was also highlighted that economic developments towards sustainability may also lead to health-related co-benefits, which may be the greatest global health opportunity of the century. For instance, a rapid phase-out of coal, and thus, the cancellation of the currently proposed construction of coal-fired power plants would result in an immediate gain for society by keeping the air cleaner, and the air would then contain fewer pollutants and less CO_2. The resulting

cleaner ambient air would reduce the health burden of particulate matter.

As summarized in [1], the greatest health-related risks of a global climate change of 1.5°C (which is most likely to occur in the next few decades) are associated with heat and malnutrition, which can be substantially reduced by appropriate adaptation.

Acknowledgements

The research leading to this paper was supported by the following sources: the Hungarian Scientific Research Fund under grant K-120605, the AGRÁRKLIMA2 project (VKSZ_12-1-2013-0034), the European Regional Development Fund and the Hungarian Government (GINOP-2.3.2-15-2016-00028).

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